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The Eastern Environmental Radiation Facility's Participation in Interlaboratory and Intralaboratory Comparisons of Environmental Sample Analyses: 1979 and 1980

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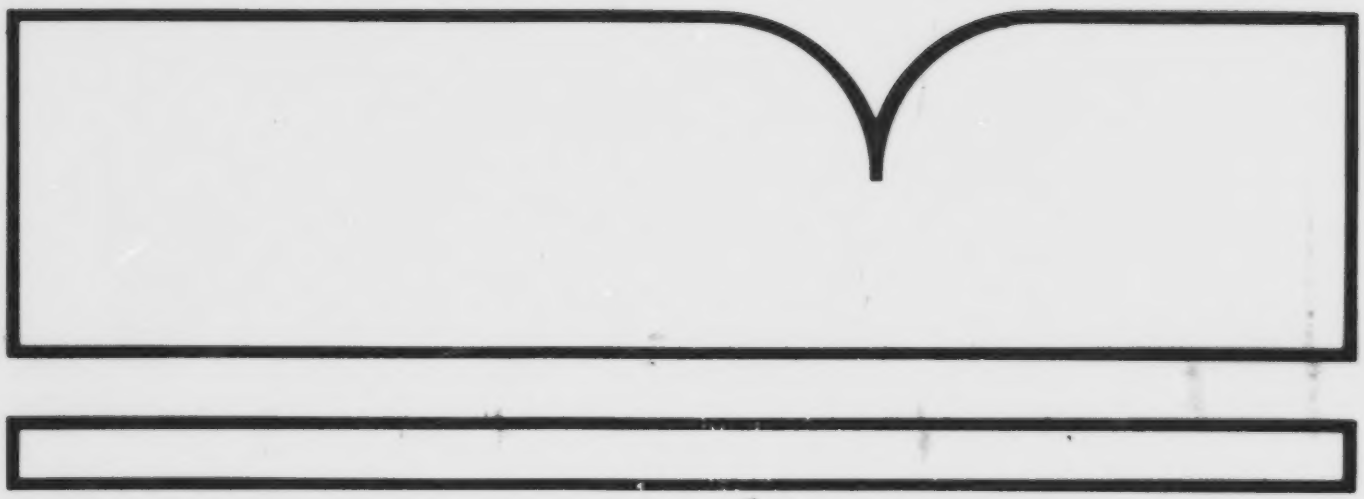

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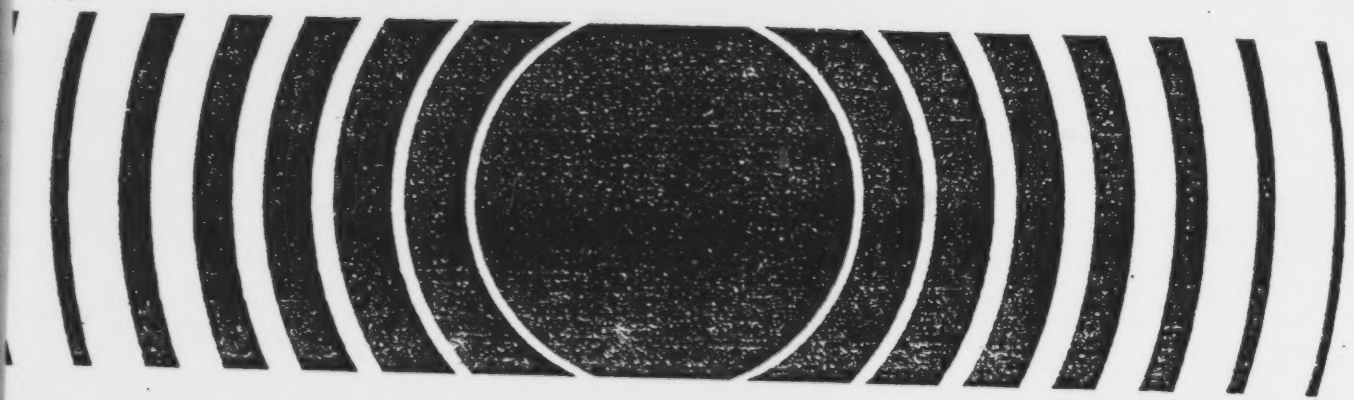

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16. ABSTRACT

Since 1964 the Eastern Environmental Radiation Facility (EERF), Office of Radiation Programs (ORP), U.S. Environmental Protection Agency, has compared its results of analyses of radionuclides in environmental and biological samples with those of other agencies. Such intercomparisons are sponsored by several agencies and the results are routinely published by the quality assurance reference center of the respective sponsoring agency. All samples in these intercomparisons are treated anonymously, identified by a code known only by the originating laboratory and appropriate reference center. The EERF is committed to making its results of interlaboratory comparison studies a matter of public record. This provides a basis for judging the validity of routinely reported results. The Environmental Measurements Laboratory (EML), formerly the Health and Safety Laboratory (HASL), was first to publish the results of their participation in an intercomparison program (We77). In 1979, the EERF followed by publishing all results of intercomparison programs prior to 1979 that were sponsored by the EPA National Quality Assurance Program at the Environmental Monitoring and Support Laboratory - Las Vegas (EMSL-LV), the World Health Organization (WHO), and the International Atomic Energy Agency (IAEA) (B179). This report presents our results for 1979 and 1980 in intercomparison studies sponsored by EMSL-LV, WHO, and the IAEA as well as our intralaboratory analyses results. The latter results include replicate, blind, and spiked sample analyses. We plan to publish similar reports on a biannual schedule.

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by
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January 1982

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PREFACE

The Eastern Environmental Radiation Facility (EERF) helps solve problems defined by the Office of Radiation Programs. The facility provides analytical capability for evaluating and assessing radiation sources through environmental studies and surveillance and analysis. The EERF provides special analytical support for Environmental Protection Agency Regional Offices and other federal government agencies as requested as well as technical assistance to the radiological health programs of state and local health departments.

Readers of this report are encouraged to comment freely. Comments may be directed to the EERF directly or to the Office of Radiation Programs in Washington, D.C.

Charles R. Porter

Director

Eastern Environmental Radiation Facility

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I. INTRODUCTION

Since 1964 the Eastern Environmental Radiation Facility (EERF), Office of Radiation Programs (ORP), U.S. Environmental Protection Agency, has compared its results of analyses of radionuclides in environmental and biological samples with those of other agencies. Such intercomparisons are sponsored by several agencies and the results are routinely published by the quality assurance reference center of the respective sponsoring agency. All samples in these intercomparisons are treated anonymously, identified by a code known only by the originating laboratory and appropriate reference center.

The EERF is committed to making its results of interlaboratory comparison studies a matter of public record. This provides a basis for judging the validity of routinely reported results. The Environmental Measurements Laboratory (EML), formerly the Health and Safety Laboratory (HASL), was first to publish the results of their participation in an intercomparison program (We77). In 1979, the EERF followed by publishing all results of intercomparison programs prior to 1979 that were sponsored by the EPA National Quality Assurance Program at the Environmental Monitoring and Support Laboratory - Las Vegas (EMSL-LV), the World Health Organization (WHO), and the International Atomic Energy Agency (IAEA) (Bl79).

This report presents our results for 1979 and 1980 in intercomparison studies sponsored by EMSL-LV, WHO, and the IAEA as

well as our intralaboratory analyses results. The latter results include replicate, blind, and spiked sample analyses. We plan to publish similar reports on a biannual schedule.

II. INTERLABORATORY COMPARISON PROGRAMS

A. EMSL-LV Intercomparison Program

The most comprehensive intercomparison program, relative to numbers of samples, sample types and radionuclides, has been conducted with the EMSL-LV Reference Center. Routine sample types and the radionuclides that were included in each are shown below:

Sample Type	Radionuclides Included in Sample
Water	$^{3}H(11)$, $^{51}Cr(6)$, $^{60}Co(10)$, $^{65}Zn(7)$, $^{89}Sr(10)$, $^{90}Sr(10)$, $^{106}Ru(8)$, $^{131}I(6)$ $^{134}Cs(10)$, $^{137}Cs(10)$, $^{226}Ra(13)$, $^{228}Ra(13)$, $^{234,238}U(5)$ $^{239}Pu(6)$, Gross Alpha (15), Gross Beta (15)
Milk	$^{89}Sr(8)$, $^{90}Sr(8)$, $^{131}I(8)$, $^{137}Cs(8)$, $^{140}Ba(8)$, K(8)
Food	$^{89}Sr(5)$, $^{90}Sr(5)$, $^{131}I(5)$, $^{137}Cs(5)$, $^{140}Ba(5)$, K(5)

Note.--The number of measurements of each type analysis is given in parentheses.

Each analysis was made in triplicate. The results of these analyses with the known concentrations are presented in Appendixes A through C. The values reported by EERF were compared in two different ways to the known values supplied by the reference center. For the first comparison, the average of the triplicate analyses (column 2)

was divided by the known concentration (column 3) resulting in a ratio (R) shown in the fourth column. The magnitude by which R differs from unity is a measure of the agreement between measured and known concentrations. However, for low concentration measurements, large values of R are often acceptable, since the uncertainty of measurement is also frequently large at low concentrations.

A second method of comparison is a qualitative statistic known as the coefficient of variation (CV) (Mo51). The coefficient of variation is particularly useful in comparing dispersion of two or more sets of positive variates measured in the same or different units. For a sample with a true mean (μ), a sample mean(X), and a sample standard deviation (S_x), the coefficient of variation (CV) is usually defined as

$$CV = \frac{S_x}{\mu} \cdot 100\%, \qquad (1)$$

where

$$S_x = \left[\frac{(X_i-\mu)^2}{n}\right]^{1/2}. \qquad (2)$$

When the true mean (μ) is not known, the coefficient of variation is defined as

$$CV = \frac{\hat{S}_x}{\bar{X}} \cdot 100\%, \qquad (3)$$

where

$$\hat{S}_x = \left[\frac{(X_i-\bar{X})^2}{n-1}\right]^{1/2}. \qquad (4)$$

There is normally a wide range of values over which radioactivity intercomparisons are made, therefore, CV is particularly useful for these applications. Equations 3 and 4 were used to compute the coefficient of variation as percent, and the results are listed in the fifth column of Appendixes A, B, and C.

The degrees of agreement between the EERF results and the concentration supplied by the reference center, as indicated by the ratio R, are summarized in Table 1. The radionuclide is given in the first column with the number of samples shown in parentheses. Results of the analyses of the different sample media--water, milk, and food--are combined. The ranges in the values of R are listed in the second column followed by the percent of the analyses differing by ± 10%, ± 20%, and by more than 20% of the known reference center value. Agreement within 10% is considered very good; those within 20% of the known value are considered satisfactory.

Approximately 80% of all EMSL-LV cross-check results were within 20% of the known value. However, 29 (64%) of the 39 EMSL-LV cross-check samples on which our results differed from the known value by more than 20% are judged satisfactory because of the low sample concentrations, the uncertainty in the measurements, and the small absolute difference between the results. These results have asterisks by them in Appendixes A through C. Thus, about 95% of the EMSL-LV cross-check analyses are acceptable by this test.

Similarly, using the coefficient of variation as a measure of consistency with the EMSL-LV cross-check samples (see values in the fifth column of Appendixes A-C), 42% had coefficients of variation within 10% of the known value; 74% were within 20%; and only 2% had coefficients of variation greater than 50%. A more detailed examination of those samples having high coefficients of variation showed that serious analytical difficulty was not indicated in most cases. For example, the ^{60}Co water cross-check of April 1980 (see

Appendix A) contained 6 pCi/l but was measured to contain 15 pCi/l, resulting in a coefficient of variation of 150%. Since the error in the analytical determination of this sample is about 8 to 10 pCi/l at the 95% confidence level, the measured value of 15 pCi/l is not significantly different from the known value of 6 pCi/l. In contrast, the results of the IAEA water sample listed in Appendix E reveal the existence of a problem in measuring ^{144}Ce. The mean concentration determined by the EERF was 112 pCi/l and the known value was only 5.6 pCi/l, resulting in a coefficient of variation of 1900%. In summary, when using the coefficient of variation to determine whether a specific analytical problem exists, one must consider both the magnitude of the measurement and the associated analytical errors.

The mean coefficients of variation for each nuclide analyzed in the EMSL-LV water, milk, and food samples are listed in the last column of Table 1. This provides a quick method for comparing the relative accuracy of the analytical procedures for different radionuclides. For example, the mean coefficient of variation of the ^{3}H analyses, 5.8%, indicates a relatively accurate procedure compared to that for ^{134}Cs, for which the mean coefficient of variation was 40%, indicating a relatively inaccurate procedure. However, this comparison does not consider the concentrations involved.

The mean coefficient of variation for ^{226}Ra of 9.4% compares favorably with the 12% value previously determined by Williams (Wi81). Also, the mean coefficients of variation of 16.8% and 14.4% for gross alpha and beta measurements, respectively, compare favorably with the 20-40% range reported by Jarvis (Ja76).

TABLE 1
Summary of EMSL-LV Cross-Check Samples

Nuclide	Range in R	Percent of values differing from R =1.00 by:			Coefficient of variation, CV (%)	
		<10%	<20%	>20%	Range	Mean
H-3(11)	0.90-1.13	64	100	0	1.5-12.7	5.8
Cr-51(3)	0.98-1.21	67	67	33	12.0-35.5	22.9
Co-60(7)	0.95-2.50	57	71	29	5.1-150.6	35.9
Zn-65(4)	0.90-1.29	75	75	25	4.4-31.6	16.7
Sr-89(18)	0.60-1.17	28	67	33	7.3-40.0	18.7
Sr-90(18)	0.93-2.78	33	78	22	3.7-178	24.5
Ru-106(3)	0.90-1.05	100	100	0	10.2-25.6	18.7
I-131(17)	0.69-1.48	53	71	29	1.2-47.5	14.9
Cs-134(8)	0.85-3.08	38	88	12	4.7-208	40.3
Cs-137(19)	0.81-1.31	79	95	5	1.7-31.6	12.2
Ra-226(13)	0.98-1.18	69	100	0	3.5-17.6	9.4
Ra-228(11)	0.57-1.50	9	27	73	3.2-49.8	30.3
U-238/234(5)	1.00-1.15	60	100	0	0 -15.4	7.9
Pu-239(6)	0.67-0.93	33	67	33	7 -33.4	16.8
Alpha (15)	0.58-1.53	40	73	27	0 -54.2	16.8
Beta (15)	0.51-1.10	53	73	27	0 -49	14.4
K (12)	0.82-1.01	83	100	0	1.0-18.2	7.9

Table 2 lists the minimum detectable concentrations for the radionuclides commonly measured by the procedures used at the EERF (Li82). These concentrations correspond roughly to one half the detection limit as defined by Currie (Cu68), in that they are a priori concentrations which should lead to detection at a confidence level of α=0.05 and β=0.05. Although results presented in this report are not sufficient to corroborate the tabulated minimum detectable concentrations, general consistency with those values is demonstrated. Of the 41 analyses of EMSL-LV cross-check samples which were reported by EERF as being below their respective detection limits, 40 were correctly reported. The analysis of only one food sample containing 8 pCi/kg of ^{89}Sr was incorrectly reported as having less than 5 pCi/kg.

B. WHO and IAEA Intercomparison Programs

While participating in the EMSL-LV intercomparison program, the EERF simutaneously participated in similar programs conducted by the World Health Organization (WHO) and the International Atomic Energy Agency (IAEA), although on a more limited basis. The intercomparison results for samples provided by these two reference centers are given in Appendixes D and E. The two programs consisted of 11 samples on which a total of 41 specific radionuclide analyses were made.

Agreement between our results and the concentrations supplied by the two international reference centers was similar to that attained in the EMSL-LV program. Seventy-one percent of the analyses agreed within 10% of the reference center value, while 84% of the analyses agreed

TABLE 2
Minimum Detectable Concentrations for Routine
Cross-Check Sample Analyses

Water Samples (pCi/l)

^{3}H - 200	^{90}Sr - 1	^{228}Ra - 1
^{51}Cr - 30	^{106}Ru - 30	^{239}Pu - 0.015
^{60}Co - 10	^{134}Cs - 10	Gross alpha - 2
^{65}Zn - 20	^{137}Cs - 10	Gross beta - 1
^{89}Sr - 5	^{226}Ra - 0.1	

Milk (pCi/l) and Food (pCi/kg) Samples

^{89}Sr - 5	^{137}Cs - 10
^{90}Sr - 1	^{140}Ba - 10
^{131}I - 10	

Soil Samples (pCi/g)

^{60}Co - 0.010	^{137}Cs - 0.010
^{106}Ru - 0.030	^{239}Pu - 0.015
^{134}Cs - 0.010	

within 20%. Of the 6 analyses that differed by more than 20% of the known concentrations, 3 are judged acceptable because of the small concentrations present (K in WHO freshwater fish, ^{90}Sr in WHO marine sediment, and ^{90}Sr in IAEA water). The concentration we reported for $^{106}Ru/^{106}Rh$ in the WHO seawater sample was for ^{106}Rh only and should have been multiplied by two to include ^{106}Ru, resulting in a total concentration of 783 pCi/l, which is 92% of the IRC value. Thus, overall agreement is quite good.

Using the coefficient of variation as a measure of consistency with the WHO and IAEA cross-check samples (see values in the fifth column of Appendixes D and E), 68% were within 10% of the known value, 84% were within 20%, and only 4 analyses had coefficients of variation greater than 50%. Discarding the coefficient of variation for the ^{144}Ce analyses of the IAEA water sample as an outlier (we are presently investigating the problem associated with the spectral analysis of ^{144}Ce), the mean coefficient of variation for all 38 analyses is 18%.

III. INTRALABORATORY COMPARISON PROGRAMS

A. Replicate Analyses

Replicate analyses are performed on every tenth sample analyzed at the EERF and on each interlaboratory cross-check sample. Usually, there were two or three replicate analyses on each cross-check sample, but some samples were analyzed as many as six times. To analyze the

precision of these analyses, we calculated the mean range ($\overline{R}$) between duplicate analyses from the standard deviation of the analyses. The mean range (Ro64; Ka77) is defined by the equation

$$\overline{R} = d_2\sigma, \tag{5}$$

where d_2 is a function of the number of replicates involved (see Table 3) and σ is the standard deviation (see Table 4). The control limits are computed as follows:

$$\overline{R} + 3\sigma = D_4\overline{R} = D_4 d_2\sigma \tag{6}$$

where σ_R is the standard deviation of the range and D_4 is a function of the number of replicates involved (see Table 3). Therefore,

$$\sigma = \overline{R}(D_4-1)/3 . \tag{7}$$

The range limits were computed for each type analysis by the procedure described above. The observed ranges between replicates were classified as $\leq(\overline{R} + \sigma_R)$, $\leq(\overline{R} + 2\sigma_R)$, $\leq(\overline{R} + 3\sigma_R)$, and $>(\overline{R} + 3\sigma_R)$. The number of replicate analyses that fall into each category is a measure of the laboratory's performance. Table 5 summarizes the results of the replicate analyses performed at the EERF. The theoretical distribution is listed in the last line of the table. Overall, the distribution of the precision attained approaches the expected theoretical distribution. Analyses showing less precision were for ^{144}Ce and ^{65}Zn.

To determine the precision of the analyses for naturally occurring radionuclides in soil, 10 identical samples of harbor silt were submitted

TABLE 3
Values Used for Calculating the Mean Range Control Limits

No. of Observations	Central line factor (d_2)	Control limit factor (D_4)
2	1.128	3.267
3	1.693	2.575
4	2.059	2.282
5	2.326	2.115
6	2.534	2.004

Source: Rosenstein and Goldin, 1964.

TABLE 4
Analytical Precision for Various Analyses

Nuclide	Concentration (pCi/l or kg)	Standard Deviation, σ (single determination)
^{89}Sr, ^{131}I, ^{137}Cs, ^{140}Ba	5-100	5 pCi/l
	>100	5%
^{90}Sr	2-30	1.5 pCi/l
	>30	5%
K	$\geq$0.1*	5%
3H	$\leq$4000	5%
	>4000	10%
^{226}Ra	$\geq$0.1pCi/l	15%
^{239}Pu	$\geq$0.1**	10%
Gross Alpha	$\leq$20	5 pCi/l
	>20	25%
Gross Beta	$\leq$100	5 pCi/l
	>100	5%

* Units are g/l or Kg.
** Units are pCi/l, g, or sample.

"blind" to the analytical laboratory. The results of the 10 replicate analyses are listed below (units are pCi/g):

$^{228}Th = 1.10 \pm 0.13$	$^{226}Ra = 1.32 \pm 0.14$
$^{230}Th = 1.42 \pm 0.27$	$^{234}U = 1.59 \pm 0.27$
$^{232}Th = 1.14 \pm 0.10$	$^{238}U = 1.44 \pm 0.21$

Each uncertainty listed is the standard deviation of an individual measurement. That is, if another analysis were to be made, the result would fall within that range 66.7% of the time. The mean standard deviation for these analyses is 13.6%, which we believe to be acceptable.

TABLE 5
Summary of Replicate Analyses Results

	Range			
Analytical Program	$\leq(\overline{R}+\sigma_R)$	$\leq(\overline{R}+2\sigma_R)$	$\leq(\overline{R}+3\sigma_R)$	$>(\overline{R}+3\sigma_R)$
EMSL-LV QA Sample analyses (n=134)	63% (85)	82% (110)	92% (123)	8% (11)
Routine analyses (n=590)	92% (542)	97% (573)	99% (584)	1% (6)
All replicate analyses made at EERF (n=724)	87% (627)	94% (683)	98% (707)	2% (17)
Theoretical distribution	84%	97.5%	100%	0

Note.--Numbers of analyses are given in parentheses.

B. Blind Analyses

A routine program of submitting water samples of known concentration to the analytical laboratory was instituted in 1980. These samples were submitted "blind" to the analytical staff with a request to perform specific analyses. The results of these analyses are reported in Table 6. The known value given in the third column of the table is either the concentration determined from previous analyses or the concentration made by "spiking" the sample. A total of 52 "blind" analyses were performed for 16 radioisotopes.

Two samples containing less than the detectable concentrations were correctly identified. Of the 50 remaining analyses, 64% of the results were within 10%, 96% were within 25%, and only 4% (2 analyses) differed by more than 30% of the known concentration. The latter two analyses were for ^{239}Pu and totaled 15% of the plutonium analyses.

TABLE 6
Results of Intralaboratory Blind Analyses of Water Samples

Date	EERF Values	Known Value	R	Date	EERF Values	Known Value	R
			^{3}H				
1/22/81	4230±300			4/28/81	1300±200	1060±50	1.23
	4280±300	4080±200	1.04				
	4200±300			4/21/80	400±200	500±200	0.80
4/16/81	8257±500						
	8241±500	8510±400	0.97				
	8231±500						
			^{40}K				
4/13/81	1048±100	1150±60	0.91				
			^{60}Co				
1/30/81	195±4	202±3	0.97	1/30/81	11±4	13±2	0.85
1/30/81	92±4	99±2	0.93				
			^{89}Sr				
8/29/80	<5	5.0	--				
			^{90}Sr				
8/29/80	6±2	7±1	0.86				
			^{106}Ru				
7/10/81	209±40	219±30	1.01	1/30/81	66±15	61±2	1.08
	232±40						

TABLE 6--Continued

Date	EERF Values	Known Value	R	Date	EERF Values	Known Value	R
			^{131}I				
10/2/80	9±7 1±7 10±7	6±1	1.11	2/18/81	123±5 121±6 121±6	138±10	0.88
10/15/80	6.9±0.6 6.3±0.9 7.4±1.0	6.8±1.4	1.01	4/13/81	69±1 68±2	75±5	0.91
			^{137}Cs				
8/29/80	11±8	<10	--	1/30/81	384±9	390±10	0.98
4/13/81	30±9 30±9	32±5	0.94	1/30/81	105±8	100±2	1.05
1/30/81	206±4	203±5	1.01	1/30/81	20±3	20±5	1.00
			^{134}Cs				
1/30/81	157±5	151±5	1.04	1/30/81	81±3	80±2	1.01
			^{210}Pb				
12/11/80	18±4	21±2	0.86				

TABLE 6--Continued

Date	EERF Values	Known Value	R	Date	EERF Values	Known Value	R
			^{222}Rn				
4/15/81	12.8±0.4	12±1	1.07	5/18/81	24±1	24±2	1.00
4/15/81	30.5±0.9	30±2	1.02	5/18/81	6.0±0.3	6±1	1.00
4/15/81	55±2	60±5	0.92	5/18/81	12.1±0.4	12±2	1.01
			^{226}Ra				
8/15/80	17.8±0.2	16±1	1.11	9/12/80	28.1±0.2	26±2	1.08
			^{230}Th				
2/8/81	54±4	65±5	0.83				
			^{238}U				
8/7/80	2.5±0.4	2.8±0.3	0.89	2/5/81	28±3	28±2	1.00
10/9/80	5.6±0.7	5.6±0.3	1.00	6/1/81	37±5	45±3	0.82
11/7/80	28±3	28±3	1.00				

TABLE 6--Continued

Date	EERF Values	Known Value	R	Date	EERF Values	Known Value	R
			^{238}Pu				
9/5/80	15±2	20±2	0.75	10/21/80	33±1	30±2	1.10
			^{239}Pu				
9/5/80	12±2	15±3	0.80	3/24/81	19±2	20±3	0.95
3/4/81	4.2±0.2	4.0±0.6	1.05	6/1/81	11±1	14±2	0.79
3/4/81	3.8±0.4	4.0±0.6	0.95	7/10/81	4.4±0.4	5.7±0.6	0.77
3/4/81	4.0±0.6	4.0±0.6	1.00	7/10/81	4.7±0.6	5.7±0.6	0.82
3/24/81	16±2	20±3	0.80	7/10/81	3.9±0.3	5.7±0.6	0.68
3/24/81	8.3±0.8	20±3	0.42				

Note.--The known value is either the concentration determined from previous analyses or the concentration made by spiking the sample.

IV. SUMMARY

This report compiles the results of the EERF's interlaboratory and intralaboratory quality assurance programs during 1979 and 1980. The interlaboratory program consisted of participating in cross-check analyses with the EMSL-LV, IAEA, and WHO Reference Centers. The intralaboratory program consisted of blank, blind, spiked, and replicate sample analyses. In general, the results were similar to those observed in previous years, and we believe them to be satisfactory.

A summary of the results from the EMSL-LV cross-check sample program is presented in Table 1. These results are also presented graphically in Fig. 1, where the cumulative probability is plotted with the observed percent error in increments of 5%. The probability that the result of an analysis will be within a selected error of the true concentration during the reporting period can be easily ascertained from the graph. For example, the probability that an analysis will be within 25% of the correct concentration is seen to be 86%. One percent of the analyses were in error by more than 50%. However, this graph does not consider those results judged acceptable because of low sample concentrations and the larger uncertainty in the results of those analyses. With these additional samples included, about 95% of the cross-check analyses were judged satisfactory.

In Fig. 2, the percent coefficient of variation is plotted with the cumulative percent of samples. This figure gives an effective

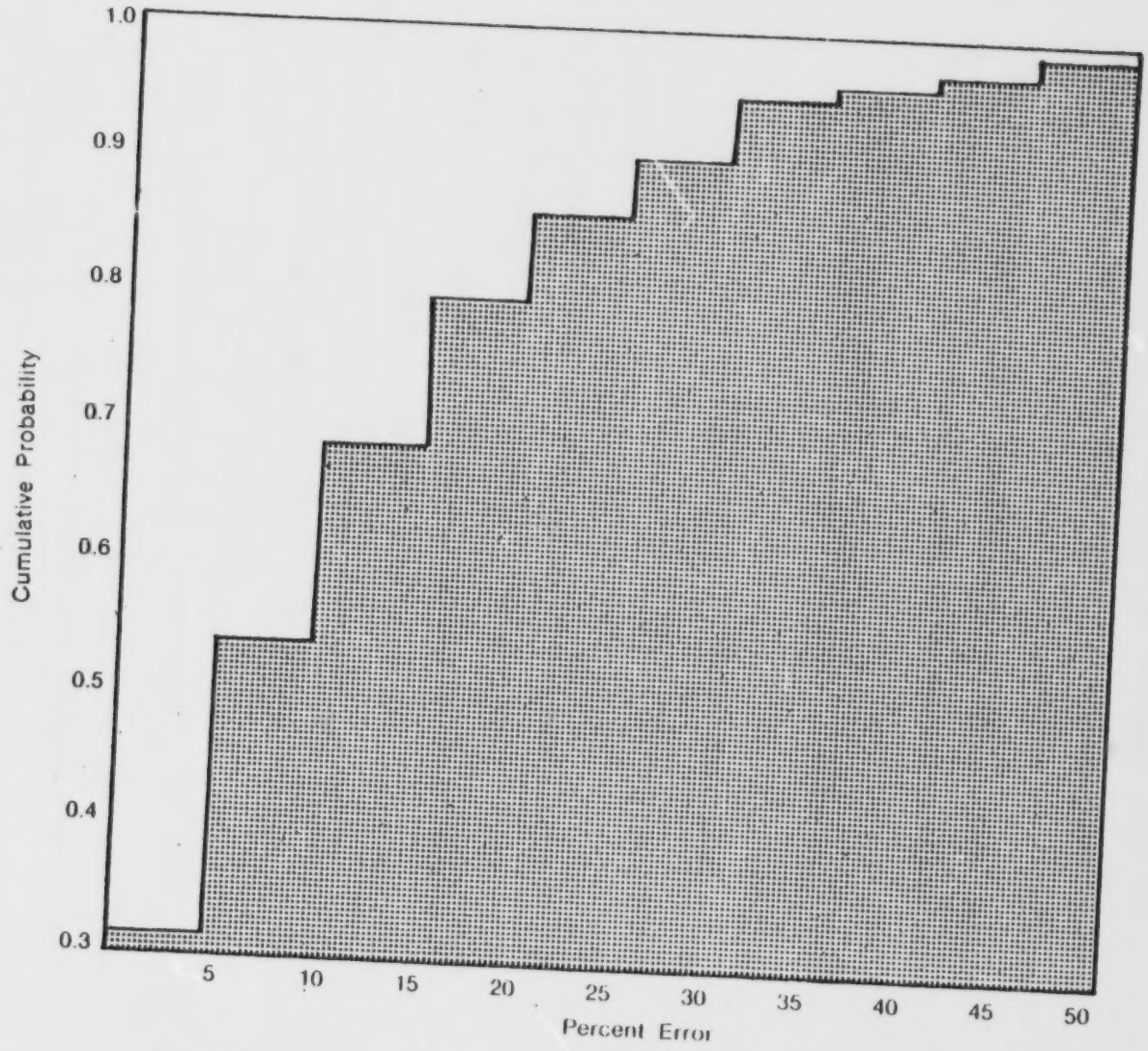

Fig. 1. Cumulative probability vs. the percent sample measurement error

standard deviation for all sample types as calculated from the normalized variances measured with respect to each known value. Similar to the results shown in Fig. 1, this figure shows coefficients of variation less than 25% for 80% of the samples. Approximately 2% of the sample results had coefficients of variation greater than 50%.

In general, the results of the intralaboratory quality assurance program were also satisfactory. The distribution of the precision attained for all replicate analyses performed during 1979 and 1980 approached the expected theoretical distribution (see Table 5). Also, the results of 96% of the blind or spiked sample analyses were within 25% of the known concentrations.

The most important function of the quality assurance program described in this report is to identify problem areas in our analytical laboratory. If a problem exists, immediate remedial action is initiated. As is apparent in some of our reported results, errors can occur for many reasons--improperly following a tested procedure, arithmetical errors in the calculations, permitting contamination to enter the sample during analysis, undetected fluctuations in counting efficiencies and backgrounds, and using incorrect weights, absorption factors, and abundances. It requires continual alertness and expedient action to recognize and correct these problems when they arise.

The EERF is continually trying to improve the quality of its analytical chemistry program. For example, a major problem that has plagued the quality of some of our analytical results has been the stripping of complex gamma-ray spectra. To remedy this problem, we are now converting the matrix method to a more general least-squares method of spectral stripping.

In accord with our belief that laboratory quality results should be public record, the EERF plans to issue in the future brief biannual reports similar to this which will present the results of our quality assurance programs.

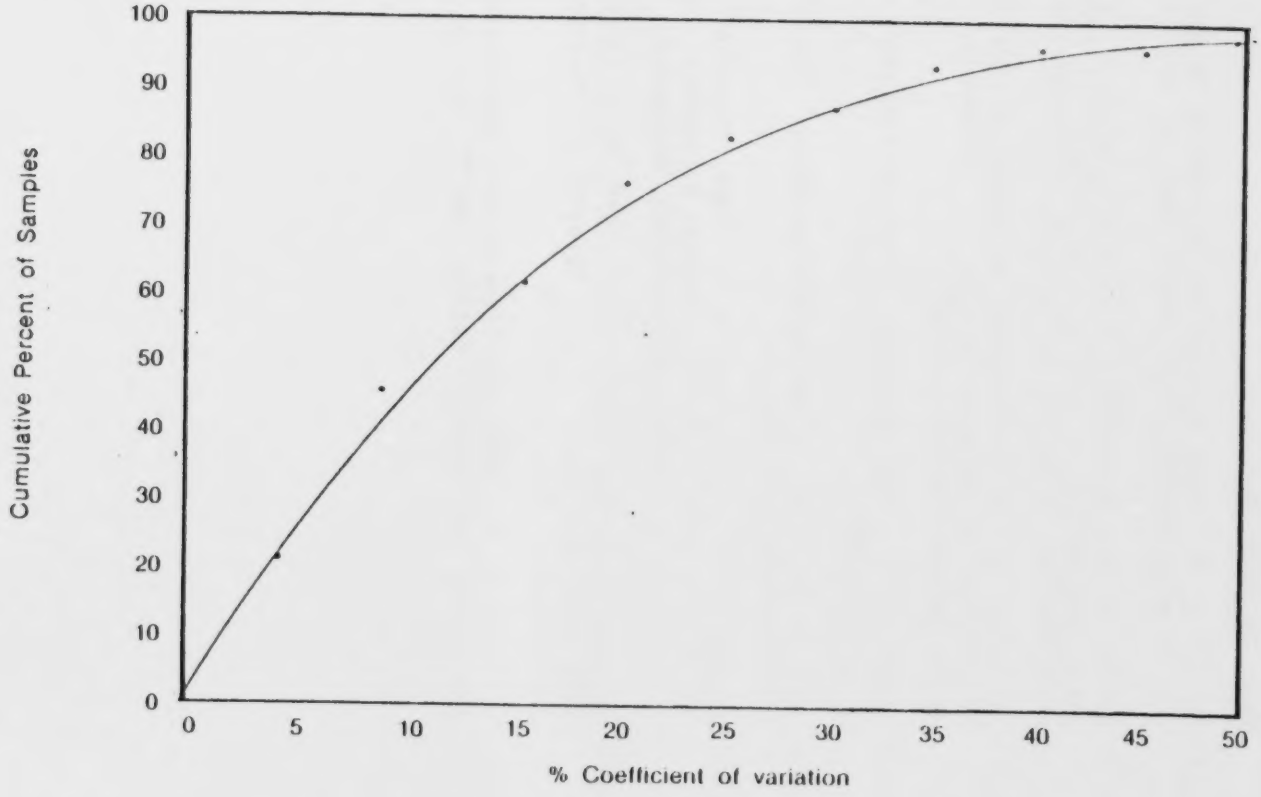

Fig. 2. The cumulative probability vs. the sample coefficient of variation

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Appendix A--EMSL-LV Water Cross-Check Samples (pCi/l)

Date	EERF Values	Known Value	R	Coeff. of Var.(%)	Date	EERF Values	Known Value	R	Coeff. of Var.(%)
				^{3}H					
4-79	2370 2310 2370	2270	1.04	3.7	4-80	3430 3480 3420	3400	1.01	1.5
6-79	1650 1780 1690	1538	1.11	11.5	6-80	2160 2180 2130	2000	1.08	7.9
8-79	1530 1540 1500	1480	1.03	3.2	8-80	1340 1340 1350	1210	1.11	11.0
10-79	1730 1720 1740	1560	1.11	10.9	10-80	3270 3210 3240	3200	1.01	1.5
12-79	1960 1950 1950	2040	0.96	4.2	12-80	2550 2510 2510	2240	1.13	12.7
2-80	1620 1560 1530	1750	0.90	10.5					
				^{51}Cr					
2-79	<50 <50 <50	0	--	--	2-80	101 103 163	101	1.21*	35.5
6-79	<30 <30 <30	0	--	--	6-80	<20 <20 <20	13	--	--
10-79	117 120 135	113	1.10	12.0	10-80	105 61 87	86	0.98	21.1

Appendix A--Continued

Date	EERF Values	Known Value	R	Coeff. of Var.(%)
2-79	<10			
	<10	9	--	--
	<10			
4-79	14			
	15	15	1.07	15.9
	19			
6-79	44			
	45	47	0.95	5.1
	45			
10-79	<10			
	<10	6	--	--
	<10			
10-79(A)	39			
	41	33	1.22*	22.4
	41			
2-79	17			
	19	21	0.90	12.3
	21			
6-79	<20			
	<20	0	--	--
	<20			
10-79	<20			
	<20	0	--	--
	<20			
2-80	33			
	33	25	1.29*	29.6
	31			
^{60}Co				
2-80	11			
	15	11	1.03	26.2
	8			
4-80	14			
	15	6	2.50*	150.6
	16			
6-80	<10			
	<10	5	--	--
	<10			
10-80	20			
	20	16	1.15	20.7
	15			
10-80(A)	13			
	12	12	1.08	10.8
	14			
^{65}Zn				
6-80	22			
	22	23	0.96	4.4
	22			
10-80	20			
	34	25	0.93	31.6
	16			
10-80(A)	<10			
	<10	0	--	--
	<10			

Appendix A--Continued

Date	EERF Values	Known Value	R	Coeff. of Var.(%)	Date	EERF Values	Known Value	R	Coeff. of Var.(%)
				^{89}Sr					
1-79	16				1-80	6			
	15	14	1.14	15.4		6	10	0.60*	40.0
	17					6			
4-79	8				4-80	3			
	6	9	0.74*	28.0		3	4	0.75*	25.0
	6					3			
5-79	20				5-80	<5			
	22	23	0.96	8.3		<5	5	--	--
	24					<5			
9-79	<5				9-80	26			
	<5	3	--	--		26	24	1.08	8.3
	<5					26			
10-79(A)	11				10-80(A)	7			
	10	12	0.89	11.8		7	6	1.17	16.7
	11					7			
				^{90}Sr					
1-79	7				1-80	23			
	7	6	1.11	13.6		26	20	1.17	19.6
	6					21			
4-79	9				4-80	<1			
	10	8	1.17	17.7		<1	0	--	--
	9					<1			
5-79	33				5-80	15			
	33	30	1.03	10.0		14	12	1.25*	25.9
	27					16			

Appendix A--Continued

Date	EERF Values	Known Value	R	Coeff. of Var.(%)
9-79	32			
	32	28	1.13	13.2
	31			
10-79(A)	8			
	8	7	1.14	14.3
	8			
2-79	<30			
	<30	0		
	<30			
6-79	<30			
	<30	0	--	--
	<30			
10-79	<30			
	<30	0	--	--
	<30			
2-80	56			
	37	51	1.05	25.6
	68			
4-79	59			
	59	40	1.48	47.5
	59			

^{106}Ru

Date	EERF Values	Known Value	R	Coeff. of Var.(%)
4-80	ND			
	ND	37	--	--
	ND			
6-80	34			
	34	37	0.90	10.2
	32			
10-80	42			
	35	46	0.97	20.2
	57			
10-80(A)	<10			
	<10	0	--	--
	<10			

^{131}I

Date	EERF Values	Known Value	R	Coeff. of Var.(%)
9-80	17			
	18	15	1.20	20.7
	19			
10-80(A)	<1			
	<1	0	--	--
	<1			
4-80	32			
	25	44	0.69	32.3
	34			

Appendix A--Continued

Date	EERF Values	Known Value	R	Coeff. of Var. (%)	Date	EERF Values	Known Value	R	Coeff. of Var. (%)
8-79	26 29 26	26	1.04	6.7	8-80	29 26 29	36	0.78*	22.6
12-79	47 50 50	53	0.92	8.0	12-80	20 20 20	22	0.91	9.1
				^{134}Cs					
2-79	<10 <10 <10	6	--	--	2-80	9 9 12	10	1.00	14.1
4-79	21 23 24	19	1.19	20.4	4-80	24 25 25	8	3.08	208.4
6-79	67 70 67	71	0.96	4.7	6-80	14 7 8	11	0.88	30.6
10-79	<10 <10 <10	7	--	--	10-80	18 16 17	20	0.85	15.6
10-79(A)	52 55 59	56	0.99	5.3	10-80(A)	10 16 14	12	1.11	23.6
				^{137}Cs					
2-79	13 11 12	12	1.00	6.8	2-80	30 35 25	30	1.00	13.6
4-79	<10 <10 <10	0	--	--	4-80	23 24 24	18	1.31*	31.6

Appendix A--Continued

Date	EERF Values	Known Value	R	Coeff. of Var. (%)
6-79	<10			
	<10	0	--	--
	<10			
10-79	17			
	11	11	1.18	31.5
	11			
10-79(A)	<10			
	<10	0	--	--
	<10			
				^{226}Ra
3-79	9.4			
	9.4	8.2	1.15	15.1
	9.5			
4-79	6.8			
	7.2	5.9	1.16	16.5
	6.5			
6-79	7.9			
	8.4	8.4	0.98	3.5
	8.5			
9-79	11.2			
	11.4	10.2	1.10	10.2
	11.2			
10-79	11.2			
	11.4	10.2	1.10	10.2
	11.1			
10-79(A)	11.2			
	11.8	11.0	1.05	5.1
	11.5			

Date	EERF Values	Known Value	R	Coeff. of Var. (%)
6-80	18			
	21	17	1.10	14.0
	17			
10-80	12			
	10	12	0.97	10.8
	13			
10-80(A)	18			
	20	20	0.95	6.4
	19			
3-80	16.2			
	17.0	16.0	1.03	3.8
	16.3			
4-80	17.4			
	17.6	16.0	1.09	9.2
	17.4			
6-80	2.0			
	2.0	1.7	1.18	17.6
	2.0			
9-80	14.2			
	13.7	13.1	1.07	7.6
	14.3			
10-80(A)	14.6			
	14.7	12.8	1.14	14.1
	14.5			

Appendix A--Continued

Date	EERF Values	Known Value	R	Coeff. of Var.(%)	Date	EERF Values	Known Value	R	Coeff. of Var.(%)
12-79	10.8 11.0 11.0	11.0	0.99	1.0	12-80	12.4 13.9 14.7	13.2	1.04	8.0
				^{228}Ra					
3-79	7.0 9.2 9.7	13.6	0.63*	37.5	3-80	ND ND ND	2.6	--	--
4-79	4.0 4.3 5.1	6.2	0.72*	28.9	4-80	31.6 31.3 ND	21	1.50	49.8
6-79	9.1 9.7 9.5	14.4	0.66*	34.5	6-80	1.0 1.0 2.0	1.7	0.78*	35.1
9-79	8.8 8.2 9.7	12.7	0.70*	30.3	9-80	14.4 13.7 14.0	14.4	0.97	3.2
10-79	8.8 8.2 9.7	12.7	0.70*	30.3					
10-79(A)	0.6 0.6 0.5	0	--	--	10-80(A)	11.9 9.6 10.4	9.2	1.16	18.7
12-79	0.4 0.5 0.8	1.0	0.57*	46.5	12-80	12.6 12.4 12.4	10.5	1.19	18.8
				$^{238/234}U$					
2-79	40 38 41	35	1.13	13.8	8-80	28 28 28	27	1.04	3.7

Appendix A--Continued

Date	EERF Values	Known Value	R	Coeff. of Var.(%)	Date	EERF Values	Known Value	R	Coeff. of Var.(%)
8-79	38 37 39	33	1.15	15.4	10-80(A)	5 5	5	1.00	0
2-80	34 35 33	32	1.06	6.8					
				^{239}Pu					
1-79	4.6 4.4 4.4	4.8	0.93	7.2	5-80	6 7 6	8	0.79*	21.7
7-79	2.1 2.1 2.1	2.4	0.88	12.5	7-80	2.8 3.2 3.0	4.5	0.67*	33.4
1-80	3.2 3.2 3.1	3.4	0.93	7.0	11-80	5.4 5.9 6.3	7.2	0.81	19.2
				Gross Alpha					
1-79	6 6 6	6	1.00	0					
3-79	11 11 10	10	1.07	8.2	3-80	12 11 11	13	0.87	13.3

Appendix A--Continued

Date	EERF Values	Known Value	R	Coeff. of Var. (%)	Date	EERF Values	Known Value	R	Coeff. of Var. (%)
4-79	24 23 23	22	1.06	6.4	4-80	57 57 57	98	0.58	41.8
5-79	19 20 18	18	1.06	7.2	5-80	23 23 23	23	1.00	0
9-79	8 8 7	5	1.53*	54.2	7-80	31 31 31	36	0.86	13.9
10-79(A)	17 18 18	21	0.84	16.0	9-80	25 24 24	32	0.76*	24.0
11-79	10 10 9	12	0.81	19.8	10-80(A)	43 43 44	39	1.11	11.2
1-80	21 20 21	30	0.69	31.2	11-80	16 16 17	16	1.02	3.6
				Gross Beta					
1-79	12 12 11	16	0.73*	27.2					

Appendix A--Continued

Date	EERF Values	Known Value	R	Coeff. of Var.(%)	Date	EERF Values	Known Value	R	Coeff. of Var.(%)
3-79	16				3-80	19			
	17	16	1.02	3.6		20	22	0.89	10.8
	16					20			
4-79	31				4-80	51			
	33	44	0.73*	27.3		51	100	0.51	49.0
	32					51			
5-79	23				5-80	16			
	21	22	1.05	8.7		15	14	1.10	10.1
	25					15			
9-79	41				7-80	34			
	38	40	0.99	3.2		31	38	0.84	16.2
	40					31			
10-79(A)	44				9-80	20			
	47	49	0.92	8.7		20	21	0.95	4.8
	44					20			
11-79	24				10-80(A)	47			
	21	27	0.85	15.7		47	60	0.79*	21.1
	24					48			
1-80	41				11-80	13			
	40	45	0.90	10.4		13	13	1.00	0
	40					13			

Notes: (1) R - The ratio of the average EERF value divided by the known value.
(2) Coeff. of var. (%) - The percent of the coefficient of variation.
(3) Date(A)-Blind performance evaluation study for radionuclides in water.
(4) ND - Not determined.
(5) Asterisk(*) indicates results which differed from the EMSL-LV value by more than 20% but were judged acceptable because of low sample concentration, the uncertainty in the measurement, and the small absolute difference.

Appendix B--EMSL-LV Milk Cross-Check Samples (pCi/l)

Date	EERF Values	Known Value	R	Coeff. of Var. (%)	Date	EERF Values	Known Value	R	Coeff. of Var. (%)
				^{89}Sr					
1-79	27 29 30	33	0.87	13.7	1-80	ND ND ND	10		
4-79	25 25 26	42	0.60	39.7	4-80	10 11 9	10	1.00	8.2
7-79	<5 <5 <5	5	--	--	7-80	51 51 51	55	0.93	7.3
11-79	16 18 16	25	0.67*	33.5	10-80	23 23 23	23	1.00	0
				^{90}Sr					
1-79	22 19 21	19	1.09	11.0	1-80	ND ND ND	25		
4-79	56 56 56	54	1.04	3.7	4-80	16 15 17	15	1.07	8.6
7-79	13 13 12	11	1.15	15.7	7-80	19 18 16	17	1.04	8.3
11-79	21 21 21	17	1.24*	23.5	10-80	<1 <1 <1	0	--	--

Appendix B--Continued

Date	EERF Values	Known Value	R	Coeff. of Var. (%)	Date	EERF Values	Known Value	R	Coeff. of Var.(%)
				^{131}I					
1-79	108 101 106	105	1.00	2.8	1-80	<10 <10 <10	0	--	--
4-79	95 95 94	96	0.99	1.5	4-80	38 42 36	33	1.17	18.8
7-79	19 19 20	17	1.14	14.0	7-80	<10 <10 <10	0	--	--
11-79	628 639 628	637	0.99	1.2	10-80	12 13 12	18	0.69*	31.6
				^{137}Cs					
1-79	52 50 51	49	1.04	4.4	1-80	ND ND ND	40	--	--
4-79	156 158 154	154	1.01	1.7	4-80	27 28 26	28	0.96	4.6
7-79	13 15 11	12	1.08	16.0	7-80	27 28 30	35	0.81	19.4

Appendix B--Continued

Date	EERF Values	Known Value	R	Coeff. of Var. (%)	Date	EERF Values	Known Value	R	Coeff. of Var. (%)
11-79	46 48 50	49	0.98	3.9	10-80	23 25 22	21	1.11	12.6
				^{140}Ba					
1-79	<10 <10 <10	0	--	--	1-80	ND ND ND	0	--	--
4-79	<10 <10 <10	0	--	--	4-80	<10 <10 <10	0	--	--
7-79	<10 <10 <10	0	--	--	7-80	<10 <10 <10	0	--	--
11-79	<10 <10 <10	0	--	--	10-80	<10 <10 <10	0	--	--
				K(mg/l)					
1-79	1420 1440 1480	1560	0.93	7.4	1-80	ND ND ND	1600	--	--

Appendix B--Continued

Date	EERF Values	Known Value	R	Coeff. of Var. (%)	Date	EERF Values	Known Value	R	Coeff. of Var.(%)
4-79	1350 1450 1390	1560	0.90	10.8	4-80	1160 1150 1160	1190	0.97	2.8
7-79	1470 1550 1430	1630	0.91	9.5	7-80	1460 1460 1430	1550	0.94	6.5
11-79	1340 1380 1420	1470	0.94	6.5	10-80	1340 1430 1410	1700	0.82	18.2

Notes: (1) R - The ratio of the average EERF value divided by the known value.
(2) Coeff. of Var. (%) - The percent of the coefficient of variation.
(3) ND - Not determined.
(4) Asterisk(*) indicates results which differed from the EMSL-LV value by more than 20% but were judged acceptable because of low sample concentration, the uncertainty in the measurement, and the small absolute difference.

Appendix C--EMSL-LV Food Cross-Check Samples (pCi/kg)

Date	EERF Values	Known Value	R	Coeff. of Var.(%)	Date	EERF Values	Known Value	R	Coeff. of Var.(%)
				^{89}Sr					
3-79	37 31 31	48	0.69	31.8					
7-79	<5 <5 <5	8	--	--	7-80	75 79 77	94	0.82	18.2
11-79	63 57 61	73	0.83	17.7	11-80	7 7 7	8	0.88	12.5
				^{90}Sr					
3-79	27 29 28	22	1.27*	27.5					
7-79	9 8 8	3	2.78*	178	7-80	18 14 18	18	0.93	12.8
11-79	33 30 31	27	1.16	16.7	11-80	<1 <1 <1	0	--	--
				^{131}I					
3-79	90 88 88	90	0.99	1.8					
7-79	20 22 22	18	1.19	19.2	7-80	58 55 58	54	1.06	6.1
11-79	124 119 134	127	0.99	5.0	11-80	26 24 26	34	0.75*	25.6

Appendix C--Continued

Date	EERF Values	Known Value	R	Coeff. of Var. (%)	Date	EERF Values	Known Value	R	Coeff. of Var.(%)
				^{137}Cs					
3-79	70 73 75	74	0.98	3.3					
7-79	35 35 32	33	1.03	5.2	7-80	27 30 28	27	1.05	6.8
11-79	22 24 15	22	0.92	19.1	11-80	12 13 8	12	0.92	19.8
				^{140}Ba					
3-79	<10 <10 <10	0	--	--					
7-79	<10 <10 <10	0	--	--	7-80	<10 <10 <10	0	--	--
11-79	<10 <10 <10	0	--	--	11-80	<10 <10 <10	0	--	--
				K(mg/kg)					
3-79	2722 2741 2694	2700	1.01	1.0					
7-79	2590 2570 2640	2650	0.98	2.2	7-80	2550 2520 2450	2660	0.94	6.0

Appendix C--Continued

Date	EERF Values	Known Value	R	Coeff. of Var.(%)	Date	EERF Values	Known Value	R	Coeff. of Var.(%)
11-79	1240 1300 1310	1511	0.85	15.2	11-80	2340 2290 2310	2520	0.92	8.2

Notes: (1) R- The ratio of the average EERF value divided by the known value.
(2) Coeff. of Var. (%) - The percent of the coefficient of variation.
(3) ND- Not determined.
(4) Asterisk(*) Indicates results which differed from the EMSL-LV value by more than 20% but were judged acceptable because of low sample concentration, the uncertainty in the measurement, and the small absolute difference.

Appendix D--WHO Intercomparison Sample Results

Nuclide	EERF Values	IRC Value	R	Coeff. of Var. (%)	Nuclide	EERF Values	IRC Value	R	Coeff. of Var. (%)
Freshwater Fish (No. F290) November 1979									
Sr-90(pCi/kg)	6130±251 6020±235 5860±252	63400±300	0.95	5.3	U(μg/kg)	1770±248 1815±254 1368±287	1620±370	1.02	12.6
Cs-137(pCi/kg)	1500±750 1500±750 1600±800	1470±90	1.04	5.4	Ca(g/kg)	58±5 58±6 58±6	62±2	0.94	6.4
Ra-226(pCi/kg)	3620±36 3820±38 3860±39	3500±700	1.08	8.2	K(g/kg)	10±1 12±1 11±2	9±1	1.22	2.4
Marine Sediment (No. E114) December 1977 (pCi/g)									
Sr-90	0.14±0.10 0.15±0.10 0.16±0.10	0.21±0.02	0.71	29	Cs-137	0.17±0.3 0.17±0.3 0.17±0.3	0.18±0.01	0.92	8.1
Ru-106/Rh-106	6.6±0.7 6.4±0.7 6.5±0.7	6.4±0.3	1.02	2.0	Ce-144/Pr-144	4.6±0.5 4.4±0.5 4.3±0.5	4.3±0.2	1.03	4.2
Liquid Milk (No. E414) March 1978									
Sr-90(pCi/l)	15±4 15±3	16.0±0.8	0.92	8.8	Cs-137(pCi/l)	34±10 32±10	31±1	1.02	7.0
Rainwater (No. F856) October 1980 (pCi/l)									
H-3	4920±450 4470±450 4860±450	4640±40	1.02	4.9					

Nuclide	EERF Values	IRC Value	R	Coeff. of Var. (%)	Nuclide	EERF Values	IRC Value	R	Coeff. of Var. (%)
				Cereals (No. F553) March 1980					
Sr-90(pCi/kg)	20±5 20±5 20±5	18±1	1.11	11.1	Ca(g/kg)	0.36±0.04 0.36±0.04 0.36±0.04	0.40±0.02	0.90	10.0
Cs-137(pCi/kg)	<5 <5 <5	5.9±0.4	--	--	K(g/kg)	5.0±0.5 4.6±0.5 4.4±0.4	4.4±0.2	1.06	8.3
Ra-226(pCi/kg)	17.0±0.9 16.6±0.8 12.4±0.7	4.2±1	3.65	270	U(µg/kg)	1.9±0.7 1.3±0.6 1.3±0.6	<0.4	--	--
				Seawater (No. F712) June 1980 (pCi/l)					
Sr-90	46±7 45±7 46±8	53±5	0.86	13.9	Sb-125	47±12 53±15 48±11	42±8	1.17	18.5
Ru-106/Rh-106*	405±61 388±54 382±57	850±70	0.46	54	Cs-137	<5 <5 <5	1.3±0.1	--	--
Ca(g/l)	1.2±0.1 1.2±0.1 1.1±0.1	1.13±0.03	1.03	5.3	K(g/l)	1.6±0.2 1.5±0.2 1.5±0.2	1.48±0.04	1.04	4.8
				Pond Water Samples (Nos. E888,889) October 1978(pCi/l)					
H-3	5500±400 5400±400 5600±400	5760±260	0.95	4.7	H-3	19,100±600 19,200±600 18,800±600	19,100±900	1.00	0.96

* Failed to multiply the Rh-106 concentration by two to include Ru-106.

Appendix D--Continued

Nuclide	EERF Values	IRC Value	R	Coeff. of Var. (%)	Nuclide	EERF Values	IRC Value	R	Coeff. of Var. (%)
				Liquid Milk (No. F140) June 1979					
Sr-90(pCi/l)	47±7 47±7 46±7	42±2	1.11	11.2	Ca(g/l)	1.2±0.2 1.2±0.2 1.2±0.2	1.23±0.03	0.98	2.4
Cs-137(pCi/l)	292±25 283±25 281±25	250±7	1.14	14.3	K(g/l)	1.4±0.2 1.5±0.2 1.5±0.2	1.55±0.04	0.95	6.2
				Low-Level Radioactive Liquid Waste (No. F100) March 1979					
H-3(μCi/l)	2.4±0.2 2.3±0.2 2.3±0.2	2.5±0.1	0.93	6.9	Co-58(pCi/l)	47,400±510 47,700±510 47,000±510	51,800±1,700	0.91	8.6
Mu-54(pCi/l)	723±110 726±110 742±110	780±70	0.94	6.5	Co-60(pCi/l)	2,300±200 2,400±200 2,400±200	2,310±120	1.02	3.2

Appendix E--IAEA Intercomparison Sample Results

Nuclide	EERF Values	True Value	R	Coeff. of Var. (%)	Nuclide	EERF Values	True Value	R	Coeff. of Var. (%)
				Water (No. W-1/2) pCi/l					
H-3	2200±200 2400±200 2500±200	2,330	1.02	5.6	Ce-144	103±52 115±58 118±59	5.6	20	1900
Sr-90	7.4±1.6 7.6±1.7 7.2±1.6	4.15	1.78	78					
				Liquid Milk (No. A-9/1) 1979-1980 (pCi/l)					
Sr-89	1.59	1.52	1.05	(4.6)	Cs-137	1004±20 1009±20 1003±20 1006±20 998±20	1040	0.97	3.5
Sr-90	0.86	0.87	0.99	(1.2)					